CHARACTERIZATION AND KINETIC STUDY OF ACTIVATED SLUDGE PROCESS IN PALM OIL MILL EFFLUENT (POME) TREATMENT

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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ABSTRAK

Sejak beberapa dekad yang lalu, effluen kilang kelapa sawit (*POME*) merupakan salah satu isu utama alam sekitar di negara kita. Disebabkan piawai pelepasan yang ketat, banyak kilang kelapa sawit tidak dapat mematuhi piawai yang tertakluk dalam undang-undang alam sekitar. Oleh itu, sistem penggilapan rawatan *POME* telah dikembangkan dan dilaksakan untuk meningkatkan prestasi proses rawatan biologi selepas rawatan sistem kolam. Walaupun demikian, proses rawatan biologi masih tidak dapat mencapai piawai pelepasan yang ditetapkan mungkin disebabkan reka bentuk sistem rawatan *POME* yang tidak sesuai. Bagi mencari punca kegagalan rawatan *POME* dalam pematuhan piawai pelepasan yang tertakluk dalam undang-undang, ciri-ciri *POME* and kajian kinetik rawatan *POME* telah dijalankan untuk memperolehi maklumat yang sesuai dalam rekaan bentuk sistem rawatan *POME*. Dalam kajian ini, penentuan komposisi fizikal telah dijalankan melalui proses pengeringan dan penyalaan, manakala analisis penagihan saiz zarah (*PSD*) dijalankan melalui proses penapisan dengan menggunakan kertas turas saiz liang yang berbeza seperti 2 µm, 5 µm, 10 µm, 20 µm, 50 µm and 100 µm. Daripada keputusan kajian ini, sebanyak 46% pepejal tetap keseluruhan (*TFS*) didapati terkandung dalam pepejal keseluruhan (*TS*) dan sebanyak 63% pepejal keseluruhan terdiri daripada zarah-zarah pepejal dengan saiz 20-50 µm dan 50-100 µm. Selain itu, komposisi kimia utama dalam *POME* adalah keperluan oksigen biokimia (*BOD*) dan keperluan oksigen kimia (*COD*). Oleh itu, keperluan oksigen biokimia muktamad (L_0) telah diramalkan melalui kaedah kajian kinetik *BOD* seperti *Least Square Method*, *Fujimoto Method*, *Thomas Graphical Method*, *Log Different Method* and *Method of Moment* dengan menggunakan keputusan *BOD* 7-hari anaerobik terawat *POME*. Manakala, penentuan pecahan *COD* anaerobik terawat *POME* seperti keperluan oksigen kimia bioterurai (*bCOD*) dan keperluan oksigen kimia bioterurai mudah larut (*srbCOD*) juga telah dijalankan serentak dengan kajian kinetik proses enapcemar teraktif dalam rawatan *POME*. Daripada kajian tersebut, didapati L_0, *bCOD* dan *srbCOD* masing-masing dalan kepekatan 1,139 mg/L, 1,235 mg/L and 719 mg/L. Bagi menyiasat kesan-kesan keadaan operasi dalam kajian rawatan *POME* dengan menggunakan enapcemar teraktif, keadaan operasi seperti *pH* awal *POME*, masa pengekalan hidraulik (*HRT*), kadar muatan organik (*OLR*), pepejal terampai mudah meruap dalam campuran keras (*MLVSS*), masa pengekalan pepejal (*SRT*) dan kepekatan gula sebagai sumber karbon luaran telah dipilih dalam kajian ini. Kecekapan enapcemar teraktif dalam rawatan anaerobik terawat *POME* telah dinilaikan di bawah keadaan aerobik berdasarkan nisbah makanan dan mikroorganisma (*F/M ratio*) dalam 0.3 kg *BOD*/kg *MLVSS*/hari dan didapati keadaan operasi terbaik masing-masing adalah pada nilai 6.5 ± 0.1, 48 jam, 0.31 g BOD_3/L.hari, 2000 ± 200 mg/L, 10 hari and 50 mg/L dengan kecekapan penyingkiran *COD* dan *BOD* masing-masing sehingga 62 - 68% dan 60 – 65%. Dengan menggunakan nilai ciri-ciri *POME* dan keadaan operasi optimum, kajian kinetik rawatan *POME* dijalankan untuk memperolehi parameter kinetic. Dalam kajian ini, parameter kinetik bagi asas *COD* dan *BOD* telah didapati, di mana pekali hasil maksimum (*Y*), pekali pereputan dalam (k_d), kadar penggunaan substrat spesifik maksimum (*k*) dan pemalar-halaju-separuh (K_s) yang didapati pada nilai masing-masing 0.2369 mg *VSS*/mg *COD*, 0.1060 hari^{-1}, 2.2717 hari^{-1} and 758.7705 mg/L bagi asas *COD*, manakala nilai parameter kinetik untuk asas *BOD* masing-masing ialah 0.6718 mg *VSS*/mg BOD_3, 0.0658 hari^{-1}, 1.4136 hari^{-1} and 556.1526 mg/L. Akhirnya, nilai-nilai yang diperolehi digunakan dalam mereka sistem rawatan POME dan membuat perbandingan dengan sistem rawatan POME yang direka dengan merujuk kepada nilai-nilai piawai yang dicadangkan oleh Jabatan Alam Sekitar yang diperolehi daripada loji rawatan air kumbahan.

ABSTRACT

Due to the more stringent discharge standard of the environmental regulation, many palm oil mills are struggled to meet the compliance. Thus, the polishing treatment plant for palm oil mill effluent (POME) discharge are developed and implemented to enhance the biological treatment process after the conventional ponding system Nevertheless, the biological treatment process yet to achieve the required discharge standard due to the inappropriate system design. Thus, characterization of POME and kinetic study of POME treatment was conducted to obtain the appropriate information for the POME treatment system design. In this study, physical composition determination was carried out through the drying and ignition process of anaerobic treated POME sample for solids contents analysis and particle size distribution (PSD) analysis was conducted via filtration process by using different pore size of filter paper (namely 2 µm, 5 µm, 10 µm, 20 µm, 50 µm and 100 µm). There was about 46% of total fixed solids (TFS) had been found in total solids (TS) of POME and 63% of TS was contributed by solids particle with particle size of 20-50 µm and 50-100 µm. Besides, major contribution of chemical constituent in POME were biochemical oxygen demand (BOD) and chemical oxygen demand (COD). Hence, ultimate biochemical oxygen demand (L_0) was estimated through BOD kinetic study methods, namely Least Square Method, Fujimoto Method, Thomas Graphical Method, Log Different Method and Method of Moment after conducting the 7-days BOD testing of anaerobic treated POME sample. While COD fractional of POME, namely biodegradable COD (bCOD) and soluble readily biodegradable (srbCOD) were determined concurrent with the kinetic study of activated sludge process in POME treatment. From the study, uBOD, bCOD and srbCOD was found at 1,139 mg/L, 1,235 mg/L and 719 mg/L, respectively. In order to investigate the effect of operating conditions on POME treatment using activated sludge, the selected operating conditions in this study were initial pH, hydraulic retention time (HRT), organic loading rate (OLR), initial mixed liquor volatile suspended solids (MLVSS), solid retention time (SRT), and molasses concentration added as a carbon source. The efficiency of activated sludge was evaluated by treating the anaerobic treated POME under aerobic conditions based on the Food to Microorganism (F/M) ratio of 0.3 kg BOD/kg MLVSS.day. The best operating condition for initial pH, HRT, OLR, initial MLVSS, SRT, and molasses concentration were found to be 6.5 ± 0.1, 48 hours, 0.31 g BOD_3/L.day, 2000 ± 200 mg/L, 10 days and 50 mg/L, respectively at the removal of chemical oxygen demand (COD) and biochemical oxygen demand (BOD) in POME ranging from 62 - 68% and 60 – 65% respectively. By using the result of characterization and optimum operating condition of POME treatment, kinetic study of POME treatment by activated sludge system were carried out to obtain the kinetic parameters for the POME treatment. From this kinetic study, the kinetic parameters for COD and BOD basis had been determined for maximum yields coefficient (Y), endogenous decay coefficient (k_d), maximum specific substrate utilization rate (k) and half-velocity constant (K_s) at 0.2369 mg VSS/mg COD, 0.1060 day^{-1}, 2.2717 day^{-1} and 758.7705 mg/L for COD basis whilst the kinetic parameters value for BOD basis were 0.6718 mg VSS/mg BOD_3, 0.0658 day^{-1}, 1.4136 day^{-1} and 556.1526 mg/L, respectively. These kinetics parameters were important in designing the POME treatment system that is able to meet the standard as the design using DOE default value has been shown to under-design and failure to meet the required standard.

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LIST OF SYMBOLS

f_b	Biodegradable fraction of VSS
k	Maximum specific substrate utilization rate (day^{-1})
k_d	Endogenous decay coefficient (day^{-1})
K_s	Half-velocity constant (mg/L of BOD) or (mg/L of COD)
k_1	Reaction rate constant (1/day)
L_0	Ultimate carbonaceous BOD (mg/L)
L_r	BOD remaining after time, t (mg/L)
m	Number of data point minus one
n	No of days of incubation for the serial BOD test
Q_i	Flowrate of influent (L/day)
Q_e	Flowrate of effluent (L/day) or (Q_i - Q_w)
Q_w	Flowrate of wasted sludge (L/day)
r_g	Net rate of biomass production (mg VSS/L.day)
r_{su}	substrate utilization rate (mg/L.day)
S_e	Soluble substrate concentration in the effluent (mg/L)
S_i	Soluble substrate concentration in the influent (mg/L)
S_{eBOD}	Reciprocal substrate of BOD concentration (L/mg of BOD)
S_{eCOD}	Reciprocal substrate of COD concentration, (L/mg of COD)
t	Time (day)
U	Specific substrate utilization rate (day^{-1})
U_{BOD}	Specific substrate utilization rate of BOD (day^{-1})
U_{COD}	Specific substrate utilization rate of COD (day^{-1})
V_d	Volume of aeration tank (L) calculated by using DOE formula
V_p	Volume of aeration tank (L) calculated by using industry formula
V_r	Volume of aeration tank (L)
X	Biomass concentration in the aeration tank (mg VSS/L)
X_i	Biomass concentration in the influent (mg VSS/L)
X_e	Biomass concentration in the effluent (mg VSS/L)
X_w	Biomass concentration in the wasted sludge (mg VSS /L)
Y	Yield coefficient (mg VSS/mg BOD) or (mg VSS/mg COD)
y	BOD exerted at time t (mg/L)
y’	Rate of change of BOD (mg/L.day)

y_e	Estimated BOD (mg/L)
y_o	Observed BOD (mg/L)
θ	Hydraulic retention time (day)
θ_c	Solids retention time (days)
$1/\theta_c$	Specific growth rate (day^{-1})

LIST OF ABBREVIATIONS

ABSR	Anaerobic bench scale reactor
ASBR	Anaerobic sequencing batch reactor
ASM1	Activated sludge model 1
ASM2	Activated sludge model 2
ASM2d	Activated sludge model 2d
ASM3	Activated sludge model 3
AN	Ammoniacal nitrogen
BOD	Biochemical oxygen demand
BOD_3	Biochemical oxygen demand – 3 days, 30°C
BOD_5	Biochemical oxygen demand – 5 days, 20°C
cBOD	Carbonaceous biochemical oxygen demand
nBOD	Nitrogenous biochemical oxygen demand
uBOD	Ultimate biochemical oxygen demand
COD	Chemical oxygen demand
bCOD	biodegradable chemical oxygen demand
nbCOD	Nonbiodegradable chemical oxygen demand
pnbCOD	Particulate nonbiodegradable COD
psbCOD	Particulate slowly biodegradable chemical oxygen demand
srbCOD	Soluble readily biodegradable chemical oxygen demand
snbCOD	Soluble nonbiodegradable chemical oxygen demand
tCOD	Total chemical oxygen demand
T_bOD	Total biological demand
COD_{it}	Initial total COD
COD_{is}	Initial soluble COD
COD_{ism}	Initial mixture soluble COD
COD_{itm}	Initial mixture total COD
COD_{mb}	Mixture biomass COD
COD_{ipm}	Initial POME COD in mixture
COD_{fpm}	Final POME COD in mixture
DO	Dissolved oxygen
DOE	Department of Environment
FFB	Fresh fruit bunch

FDS	Fixed dissolved solid
FSS	Fixed suspended solid
F/M Ratio	Food to Microorganism Ratio
HRT	Hydraulic retention time
IAAB	Integrated anaerobic-aerobic bioreactor
MLSS	Mixed liquor suspended solid
MLVSS	Mixed liquor volatile suspended solid
MPOB	Malaysian Palm Oil Board
MW	Molecular weight
O&G	Oil & grease
OLR	Organic loading rate
OUR	Oxygen uptake rate
PAH's	Polycyclic aromatic hydrocarbons
PAO's	Phosphorus accumulating organism
POME	Palm oil mill effluent
PSD	Particle size distribution
SBR	Sequencing batch reactor
SRT	Solid retention time
SS COD_w	Suspended solid COD
SS COD_{im}	Initial mixture suspended solid COD
SOUR	Specific oxygen uptake rate
TCMP	2-chloro-6-(trichloromethyl) pyridine
TDS	Total dissolved solid
TN	Total nitrogen
TS	Total solid
TFS	Total fixed solid
TSS	Total suspended solid
TVS	Total volatile solid
UASB	Upflow anaerobic sludge blanket
VDS	Volatile dissolve solid
VSS	Volatile suspended solid

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